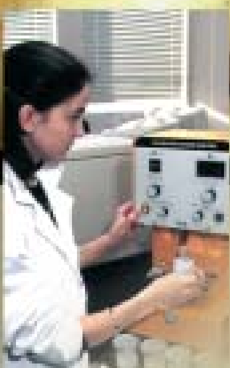
FINAL REPORT

Project Armis No. 4195

Relating Starch Properties to Boiled-Potato Texture



The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 4

Contents

RELATING STARCH PROPERTIES TO BOILED-POTATO TEXTURE

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SUMMARY

Basic information on starch properties may help to explain the different textural characteristics of potato cultivars, and also their suitability for different forms of processing. The study involved tests on both raw potatoes, and on starch separated from potatoes, and embraced three main activities:
(i) to relate boiled-potato texture with the other test variables;
(ii) to develop a rapid crush-test for assessing cooked-potato texture;
(iii) to study the effect of chilling and freezing on the development of resistant starch (RS) in boiled potatoes.

Boiled-potato texture was significantly correlated with potato dry matter content, starch peak viscosity, degree of starch retrogradation, and with starch gel compression values. However, there was a wide variation for each of these variables between potato cultivars, and sometimes between different batches of the same cultivar. This explains why it is difficult for processors to deliver a consistent texture in par-cooked or mashed potato products.

A rapid crush-to-failure technique was developed for measuring the susceptibility to heat (in texture-softening terms) of different potato cultivars and batches of potatoes. The technique is cheap, easy to perform, and was tested in-factory.

Holding mashed potato at chill or frozen temperatures gave RS values of up to 25% (on a dry matter basis). These results are relevant where potatoes are being cooked-cooled and then held chilled or frozen as in potato salad production or in chilled/frozen ready meals. RS is of nutritional significance as it behaves physiologically as dietary fibre and has only half the energy content of digestible starch.

INTRODUCTION

The potato was introduced into Ireland in the sixteenth century (1) and Ireland is now synonymous with the potato, largely due to the potato famine in the last century. While potato consumption has fallen from the massive pre-famine adult intake (by labourers and small holders) of 5-6 kg per day (2) to about 0.4 kg per person per day (3), Ireland still remains at the top of the European league for potato consumption. The area of potatoes grown in Ireland in 1997 was 15.5 kha with a yield of about 460 ktonnes (4).

Traditionally, potatoes were consumed in Ireland as boiled with skins-on, and while some are still consumed this way, there has been a swing towards French fries and crisps, and more recently towards a range of convenience potato products. This trend is a component of the rapidly growing prepared consumer foods sector in Ireland (5).

Many of the convenience ready-to-use potato products such as mash, par-cooked whole or sliced potatoes, and dice for potato salad are heat-treated. This brings its own demands in terms of the functional properties of different potato cultivars, and their starches, required for different products and end-uses. These requirements prompted the two-year research project reported here which was supported by EU structural funds.

The purpose of the study was to carry out a range of tests on starch separated from potatoes, and to link the results to the cooked (boiled) texture of the potatoes, and also to other quality parameters such as dry matter content. Basic information on starch properties will help explain the different sensory properties of potato cultivars and also their suitability for different types of processing. Put simply, – "by understanding the starch you can understand the potatoes".

The project embraced tests on the raw potatoes (dry matter content, flesh colour, cooking by boiling) and on separated starch (viscological properties of starch pastes and gels). Spectroscopic studies were also conducted. A rapid crush-to-failure technique was developed which measured the susceptibility to heat (in texture-softening terms) of different potato batches or cultivars. Attention was also focused on the development of resistant starch (RS) in boiled potatoes and especially in boiled potatoes subjected to a chilling or freezing step prior to reheating/consumption. RS is physiologically important as it has many of the properties of dietary fibre, and as such is desirable.

The potato starch project is only one of a number of recent and ongoing R&D activities at The National Food Centre for the potato processing sector. Some of these are described briefly at the end of this report under the heading "other RTD activities".

SAMPLES TESTED

The six cultivars (and their classification) tested in 1995/96 were Cara (slightly dry to slightly humid), Desirée (slightly dry to slightly humid), Maris Piper (slightly mealy to slightly dry), Rooster (mealy to dry), Kerr's Pink (very mealy to dry), and Anna (slightly mealy to slightly humid). The same cultivars were tested in 1996/97 except that Maris Piper was replaced by Barna (slightly humid to slightly dry). The samples were from field trials at Oak Park Research Centre, Co. Carlow and there were four replicates. The 1995 samples were tested in March 1996 after 4 months in an ambient potato store. The 1996 samples were tested in January 1997. These cultivars were also used for the resistant starch tests but additional tests were conducted using the cultivar Record (obtained commercially). The samples for the microwave crush test were sourced from a local potato merchant.

Seventy two potato samples (spot samples) from three commercial companies were also evaluated over a 12-month period.

DRY MATTER CONTENT AND FLESH COLOUR

Dry matter content was measured with a Zeal hydrometer (6) and flesh colour (L/b = white/yellow ratio) with a Hunter colour meter. Dry matter content is an important quality parameter with high values associated with floury texture in boiled potatoes and low values with soapy texture (7, 8). Flesh colour of the raw potato is a major determinant of the colour of the processed product.

Measuring dry matter content using a Zeal hydrometer

Table 1: Dry matter content and flesh colour of raw potatoes (1995, 1996)

	Dry matter (%)		Flesh colour (Hunter L/b; white/yellow)	
Cultivar	1995	1996	1995	1996
Cara	19.2 (5)[1]	18.5 (4)	3.17 (3)	3.14 (4)
Desirée	20.6 (4)	19.3 (3)	2.82 (5)	2.88 (5)
Maris Piper	21.1 (1)	-	3.04 (4)	-
Barna	-	17.9 (5.5)	-	3.17 (3)
Rooster	20.8 (2)	21.7 (2)	2.59 (6)	2.66 (6)
Kerr's Pink	20.7 (3)	22.7 (1)	3.78 (1)	3.73 (1)
Anna	19.0 (6)	17.9 (5.5)	3.36 (2)	3.36 (2)
Significance	P<0.01	P<0.001	P<0.001	P<0.001
LSD[2]	1.10	1.10	0.08	0.14

[1]Rank order; largest value ranked 1
[2]Least significant difference

Maris Piper potatoes had the highest dry matter content, and Anna the lowest in 1995. In 1996 Kerr's Pink was highest and Anna and Barna the joint lowest (Table 1). There was reasonable agreement in the rank order of the data for the cultivars between the two years. Kerr's Pink and Anna potatoes had the whitest flesh in both years while the yellow flesh of the Rooster potatoes gave the lowest L/b values in both years.

The dry matter data were correlated with the other test variables and the correlation coefficients are presented in Table 5.

STARCH SEPARATION

Starch was separated (non quantitatively) from both raw and frozen (thawed) potatoes by a manual grating procedure as shown in Fig 1 (9).

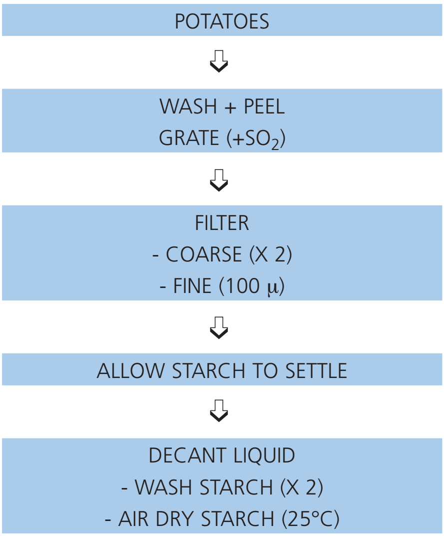


Figure 1: Starch separation

The powdered air-dried starch had an equilibrium moisture content of about 20% and protein content ranged from 0.16 to 0.27% (on a dry weight basis) indicating a good level of purity. Cara and Anna potatoes yielded the whitest starches and Rooster and Desirée the least white. Viscological tests were conducted on pastes and gels made from the starches; the content of amylose, phosphorus and trace elements in the samples was also estimated.

VISCOLOGICAL PROPERTIES OF STARCH PASTES AND GELS

The properties of starch separated from seven potato cultivars were investigated and the test variables were related to boiled-potato texture (shear values). This was achieved by preparing gels (or jellies) from the starches and measuring gel compression, gel shear (or "cutting") and gel adhesiveness (or stickiness) values. Starch properties such as peak viscosity (i.e. the maximum viscosity achieved during the heating of a starch paste) and degree of retrogradation (i.e. degree of set-back in a starch paste during cooling) were also measured using a Brabender viscograph (a slow procedure requiring a large starch sample), and the results were compared with those from the gels and from the potato boiling tests.

Starch gelatinisation

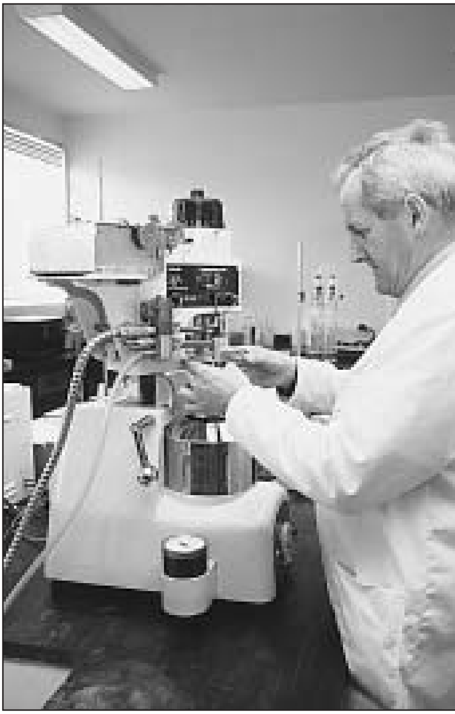
When a suspension of starch grains in water is heated, the grains swell, and the suspension thickens and reaches a maximum viscosity - termed peak viscosity, i.e. the starch gelatinises. The viscosity then begins to fall as the hydrated starch grains rupture. However, on cooling, the suspension undergoes retrogradation, or set-back, and the paste thickens and the viscosity rises again. On further cooling, the paste sets to a gel. This is due to the aggregation of the amylose molecules of the starch with each other via hydrogen-bonding. They entrap water and the resulting network is a gel. These changes in starch properties can be followed readily as they occur by measuring the viscosity of a heated/cooled starch paste in a Brabender viscograph. Alternatively, starch gels can be prepared and tested. Gel compression value is a good index of degree of starch retrogradation while the adhesiveness or stickiness value relates to the starch peak viscosity value on the Brabender viscograph.

The changes described above for starch gels and suspensions also occur for the starch grains within the cells of boiled potatoes during cooling, and so contribute to boiled-potato texture.

Starch pastes

The Brabender viscosity curve yields information on pasting time and temperature, peak viscosity, degree of starch grain rupture, degree of retrogradation, and cooked paste stability. The results for peak viscosity and degree of retrogradation are presented in Table 2 while data for the other variables will be presented elsewhere (10). Rooster and Cara potato starch grains had the greatest ability to hold water and swell without bursting (peak viscosity) (9) (Table 2). This suggests that these two cultivars can take more heat (during cooking) and can remain more intact than Anna and Desirée which had lower peak viscosity values.

Cara and Barna starches showed the highest level of retrogradation (set-back) which suggests a soapy cooked texture, while Rooster and Maris Piper starches showed the opposite effect (9). Kerr's Pink starch behaved differently in the two years with the second highest level of retrogradation in 1995 and the lowest in 1996. The Brabender viscograph data were correlated with the other test variables (see Table 5)



▲ *Brabender viscograph*

Table 2: Brabender viscograph data (BU)[1] for starch from seven potato cultivars (1995, 1996)

	Peak viscosity[2]		Degree of retrogradation[3]	
Cultivar	1995	1996	1995	1996
Cara	1348 (1)[4]	1225 (3)	643 (1)	701 (2)
Desirée	1133 (4)	1008 (5)	460 (4)	665 (3)
Maris Piper	1280 (3)	-	360 (6)	-
Barna	-	1108 (4)	-	718 (1)
Rooster	1330 (2)	1450 (1)	423 (5)	513 (5)
Kerr's Pink	1125 (5)	1395 (2)	578 (2)	443 (6)
Anna	1075 (6)	983 (6)	560 (3)	565 (4)
Significance	P<0.01	P<0.001	P<0.01	P<0.05
LSD	151	76	136	110

[1]Brabender units
[2]Maximum viscosity reading for starch paste
[3]Rise in viscosity on cooling from 94° to 50°C at 1.5°C/min
[4]Rank order; largest value ranked 1

Stevens gel tester

Starch gels

Starch gels (or jellies) were prepared by suspending starch in distilled water in 100ml beakers followed by gentle heating, microwaving, and holding at 18-20°C for 24 hr (11). The resulting gels were removed from the beakers (acting as moulds) for testing. This involved measuring compressive strength [in Newtons (N)] on a Stevens texture analyser using a cylindrical probe (25 mm diameter) followed by shearing in the standard test cell of a Kramer shear press. The negative peak obtained during blade retraction was also recorded as it provided a measure of gel adhesiveness or stickiness.

Table 3: Compression values [1] (Newtons) for gels prepared from starch from different potato cultivars (1995, 1996)

Cultivar	1995	1996
Cara	1.87 (1)[2]	1.71 (1)
Desirée	1.45 (5)	1.49 (3)
Maris Piper	1.07 (6)	-
Barna	-	1.58 (2)
Rooster	1.54 (4)	1.21 (5)
Kerr's Pink	1.81 (2)	1.04 (6)
Anna	1.71 (3)	1.31 (4)
Significance	P<0.001	P<0.01
LSD	0.14	0.20

[1]Cylindrical probe, Stevens texture analyser
[2]Rank order; largest value ranked 1

Table 4: Shear and adhesiveness values (Newtons) for gels prepared from starch from different potato cultivars (1995, 1996)

	Shear value[1]		Adhesiveness[1]	
Cultivar	1995	1996	1995	1996
Cara	182 (2)[2]	119 (4)	16.0 (6)	40.8 (2)
Desirée	185 (1)	161 (2)	18.2 (5)	22.2 (6)
Maris Piper	153 (5.5)	-	34.6 (1)	-
Barna	-	163 (1)	-	23.5 (5)
Rooster	171 (3)	130 (3)	29.2 (3)	30.8 (4)
Kerr's Pink	153 (5.5)	118 (5)	29.4 (2)	43.9 (1)
Anna	164 (4)	106 (6)	28.9 (4)	38.7 (3)
Significance	P<0.001	P<0.01	P<0.001	P<0.001
LSD	8.1	17.7	4.0	9.4

[1]Standard test cell, Kramer shear press
[2]Rank order; largest value ranked 1

There were large variations (Tables 3 and 4) in gel compression, shear and adhesiveness values both between cultivars and years. In 1995, Cara and Kerr's Pink starch gels had the highest compression values and Desirée and Maris Piper gels the lowest (Table 3). Cara and Desirée gels were the most resistant to shear while those of Maris Piper and Kerr's Pink were the most adhesive or sticky (Table 4). Gel compression values for the 1996 samples were generally lower than 1995 and Cara gels again had the highest compression values followed by Barna. Kerr's Pink gels had the lowest compression values in 1996, showing a reversal from its second highest position in 1995. Barna gels had the highest shear values in 1996 followed by Desirée gels. The value for Cara was ranked fourth among the samples in 1996 despite being ranked second in 1995 while the reverse was the case for adhesiveness values. Kerr's Pink gels were the most adhesive and those from Desirée and Barna starches the least adhesive (Table 4).

These results, overall, show a large variation in starch gel properties and suggest, therefore, a wide variation in boiled-potato texture for the different cultivars, and also in some cases for the same cultivar between 1995 and 1996. This, in effect, means that different cooking times would be needed in order to deliver a given potato texture. The data were correlated with boiled-potato texture (1996 only) and with other test variables (see Table 5).

EFFECT OF FREEZING ON STARCH PROPERTIES

The purpose of this part of the study was to investigate the effect of freezing starch grains *in-situ* in the potatoes on the viscological properties of starch pastes and gels. The potatoes (six cultivars, 1996 samples) were not blanched and were tested as peeled cylindrical cores (2.5 cm in diameter x 2.5 cm high). The cylinders were blast frozen (-35°C), held at -25°C for 1 week followed by thawing overnight at 4°C. The starch was then separated and compared with that from samples which were not frozen.

Starch pastes (Brabender viscograph) from frozen vs non frozen grains had the following values (12): pasting time (30.6 vs 28.6 min), degree of retrogradation [677 vs 601 Brabender units (BU)], cooked-paste stability

(+21.7 vs - 82.5 BU), and peak viscosity (672 vs 1195 BU). Values for the potato starch gels were: compression [1.59 vs 1.39 Newtons (N)], shear (85 vs 132 N), and adhesiveness (22.4 vs 33.3 N). Freezing, therefore, had a marked reducing effect on peak viscosity suggesting that it damaged the starch grains and rendered them less able to swell and hydrate. However, this was not reflected in particle size analysis (using a Mastersizer S) with mean diameters (mm) of 47.5 vs 42.6, 44.9 vs 49.5, 45.1 vs 47.3, 50.3 vs 48.3, 47.9 vs 44.9 and 35.9 vs 38.4 for the six starches (Cara, Desirée, Barna, Rooster, Kerr's Pink, Anna) separated from raw and frozen (unblanched) potatoes respectively. Confocal microscopy of the 12 starches (i.e. 6 from raw, and 6 from frozen/thawed potatoes) supported this finding as the starch grains were not fractured/damaged to any significant degree by freezing. The main feature of the starch diameter data was that Rooster and Anna had larger and smaller grain diameters, respectively, than starch from the other four cultivars. Pastes and gels from starch grains that had been frozen had higher values for degree of retrogradation, cooked paste stability and gel compression than those from starch that had not been frozen. This indicates an increased ability to hydrogen bond and should be reflected in a firmer (more soapy) boiled-potato texture. This was the case with mean texture (shear) values (over six cultivars) of 1215 vs 808 Newtons for boiled potatoes (tested as frozen and non-frozen cylinders). However, an increase in shear value of this magnitude could not be due solely to changes in starch properties, but may also be due to changes in the potato cell walls brought about by enzymes during the thawing and/or cooking of the unblanched potato cylinders. These data show that freezing starch *in-situ* in the potatoes had a marked effect on the viscological properties of pastes and gels made from the starch; this was also reflected in the texture of the cooked potatoes.

BOILED-POTATO TEXTURE

Shear press for measuring boiled-potato texture

Boiling tests were carried out on the 1996 potato samples but not on those from 1995 for logistic reasons. Cylinders (2.5 cm in diameter x 2.5 cm high) were cut from potatoes with a cork borer and were cooked in boiling water for 8min, cooled for 2hr, and then sheared in the standard test cell (100g samples) of a Kramer shear press. There were differences between the cultivars as follows: Anna (992 Newtons), Barna (960), Cara (780), Desirée (761), Kerr's Pink (650) and Rooster (645). These results show a wide variation in boiled-potato texture with Anna the firmest and Rooster the softest. These data were correlated with the other test variables (see Table 5).

OTHER TESTS

Starches from the different potato cultivars were tested for amylose (1995 samples only) and phosphorus (1995 samples only) content, and for the minerals copper, zinc, magnesium, calcium, sodium and potassium (1996 samples only). Amylose was measured because of its ability to hydrogen bond and, therefore, influence the viscological properties of starch pastes and gels. Phosphate groups confer the properties of a polyelectrolyte on potato starch amylopectin in aqueous solution. The mutual repulsion of the charged groups forces the molecule to expand which assists swelling and increases paste viscosity as measured on a Brabender viscograph. The minerals were tested to see if they were significantly correlated with the viscological variables of the starch pastes and gels. However, all the correlation coefficients were small.

The amylose content (% on a dry matter basis) of the starches from the different potato cultivars was different with values in descending order of 31 (Cara), 30 (Anna), 28 (Desirée), 27 (Maris Piper), 26 (Kerr's Pink) and 22 (Rooster). Starch from Cara had a much higher phosphorus content (0.106% of dry matter) than that from the other five cultivars (range 0.071 to 0.090%) (of dry matter). In the case of the minerals, there were no statistically significant differences (for their concentrations) between starches from the different potato cultivars, with the exception of copper, and the mean values (mg/100 g dry matter) were copper (1.00), zinc (0.47), iron (0.66) magnesium (11.38), calcium (15.73), sodium (7.53) and potassium (4.58). In the case of copper, starch of the cultivar Cara had a much higher content at 2.36 mg/100 g dry matter than the other five cultivars (range 0.49-0.99 mg/100 g).

Near infrared (NIR) spectroscopy was used (because of its speed) in an attempt to predict the viscological properties of the starches from the different cultivars, and also the content of resistant starch in the raw and cooked potatoes. However, this approach was unsuccessful and while quite high correlations were found between certain viscological parameters and NIR spectra, the prediction errors associated with these calibrations were greater than the standard deviation of the reference data. The fact that even the correlation coefficient magnitudes varied significantly between the experimental and commercial potato samples suggests serious instability in the models generated and confirms the inability to use NIR data for this particular application. With regard to the measurement of resistant starch in potatoes, the levels and variation of this material were too low to allow for success; prediction of moisture content was achieved with a standard error of prediction of 1.1%, slightly below the repeatability error for the reference measurements.

RELATIONSHIPS BETWEEN THE TEST VARIABLES

Rank correlation coefficients (r) (ideally 1) were calculated to determine the relationships between the variables dry matter content (raw potatoes), peak viscosity (Brabender), degree of starch retrogradation (Brabender), compression (gel), shear (gel), adhesiveness (gel), boiled-potato shear, phosphorus (starch), amylose (starch) and copper content (starch). Starch amylose and phosphorus contents were measured in 1995 only and so the correlations relating to them were for 1995. Similarly for boiled-potato shear which was carried out in 1996 only. Rank correlation coefficients were determined using the equation:

$$r = 1 - \frac{6\Sigma d^2}{n^3 - n}$$

where d is the difference between the ranks and n the number of items (i.e. 6) ranked. Correlation coefficients ≥ 0.60 (both positive and negative) are cited in Table 5.

Three relationships had r ≥ 0.60 in both years (Table 5), i.e. compression (gel) x retrogradation (Brabender), potato dry matter x retrogradation (Brabender), and potato dry matter x compression (gel). A strong relationship would be expected between compression (gel) x retrogradation (Brabender) as both relate to gel/paste setting/thickening during cooling.

Boiled-potato texture (shear) was highly correlated with potato dry matter content and to a lesser extent with starch peak viscosity (Brabender), degree of starch retrogradation (Brabender), and with gel compression value (Table 5). These data show that the total solids (mostly starch) content of potatoes, together with the properties of the starch, influence boiled-potato texture (shear). The relationships of boiled-potato texture with dry matter content and peak viscosity (Brabender) were both inverse, i.e. a high value for dry matter, or for peak viscosity, gave a soft potato texture and vice versa.

It is important to stress that the shear value only represents one element of potato texture (i.e. firmness or "cutting" value after cooking), and in-depth taste testing with an expert panel would be needed to relate other elements of texture (e.g. the mouthfeel aspects gumminess/stickiness/sliminess) to the gel and starch properties measured in these tests.

Table 5: Rank correlation coefficients ≥ 0.60 for the test variables

Variable		Rank correlation coefficient (r)
1995[1]		
Compression (gel) x retrogradation (Brabender[2])	=	+ 0.94
Shear (gel) x adhesiveness (gel)	=	- 0.84
Adhesiveness (gel) x potato dry matter	=	+ 0.77
Compression (gel) x phosphorus (starch)	=	+ 0.77
Amylose (starch) x potato dry matter	=	- 0.77
Retrogradation (Brabender) x potato dry matter	=	- 0.71
Adhesiveness (gel) x amylose (starch)	=	- 0.66
Retrogradation (Brabender) x potato dry matter	=	- 0.71
Compression (gel) x potato dry matter	=	- 0.60
Adhesiveness (gel) x retrogradation (Brabender)	=	- 0.60
1996		
Boiled-potato shear x potato dry matter	=	- 0.90
Compression (gel) x retrogradation (Brabender)	=	+ 0.94
Boiled-potato shear x peak viscosity (Brabender)	=	- 0.83
Peak viscosity (Brabender) x potato dry matter	=	+ 0.73
Retrogradation (Brabender) x potato dry matter	=	- 0.90
Boiled-potato shear x retrogradation (Brabender)	=	+ 0.60
Adhesiveness (gel) x peak viscosity (Brabender)	=	+ 0.66
Compression (gel) x potato dry matter	=	- 0.64

[1]No boiling tests in 1995
[2]Brabender viscograph

The adhesiveness or the stickiness of the gel was related to gel shear values (inverse relationship), potato dry matter content, degree of retrogradation (Brabender) (inverse relationship), and to peak viscosity (Brabender) (Table 5).

Phosphorus content of the starch was highly correlated with gel compression value presumably due to its ability to cause expansion and increased hydration in the amylopectin fraction of the starch. Because of this, it was anticipated that starch phosphorus content would also correlate highly with peak viscosity (Brabender). However, the rank correlation coefficient was only 0.55. Starch amylose content was inversely correlated with gel adhesiveness values and raw potato dry matter content (Table 5), and was positively correlated (0.55) with degree of starch retrogradation. Amylose, therefore, is associated with soapiness, rather than with flouriness, in boiled-potato texture.

DATA FOR COMMERCIAL SAMPLES

Seventy two potato samples from three commercial companies were subjected to a range of tests including dry matter content and Hunter meter colour [white/yellow (L/b)] values on the raw potatoes. The results for individual samples and cultivars have been sent to companies who supplied them but the mean data together with coefficients of variation are presented in Table 6. There was a large amount of variation associated with some of the means, notably starch grain fragmentation/bursting and cooked paste stability. The correlation coefficients for the different variables were generally significant, but small (<0.50) except for closely related variables such as pasting time vs pasting temperature which was >0.95. The small correlations were to be expected in view of the fact that there were a number of cultivars from different locations and storage regimes. Nevertheless, the data provide useful baseline information for the variables tested and also the spread, or range, in values likely to be encountered in practice.

Table 6: Mean values and coefficients of variation (%) for 12 test variables (72 commercial potato samples)

Variable[1]		Mean	Coefficient of variation (%)
1.	Pasting temp (°C)	63.6	3.1
2.	Pasting time (min)	29.0	4.5
3.	Peak viscosity (BU)	1102	23.3
4.	Grain fragmentation (BU)	-30.8	568.2
5.	Degree of retrogradation (BU)	564	33.2
6.	Cooked paste stability (BU)	-18.2	549.5
7.	Gel compression (g)	147	24.4
8.	Gel shear (N)	96.0	33.1
9.	Gel adhesiveness (N)	28.7	37.7
10.	Dry matter content (%)	20.6	7.7
11.	Flesh colour (Hunter L/b)	3.12	13.8
12.	Boiled-potato shear (N)	767	25.6

[1] Variables 1 to 6 relate to potato starch pastes (Brabender)
Variables 7 to 9 relate to potato starch gels
Variables 10 to 12 relate to raw or boiled potatoes

MICROWAVE CRUSH TEST

It is often difficult to achieve the desired texture in par-cooked potatoes due to differences in the susceptibility of different potato cultivars to heat. The heat applied influences both the starch and cell wall properties of the potato. The objective here was to develop a rapid crush-to-failure microwave test to determine the susceptibility of potato cylinders from different potato cultivars to heat treatment. The rapid crush-to-failure technique uses cylindrical cores (2.5 cm in diameter x 2.5 cm long) of potato (under a fixed load of 600 g) which are cooked in a custom-made glass flask in a microwave

Microwave crush test apparatus

oven (1000 Watt) until they collapse/fail. The cylinders are cut from the potatoes with a cork borer. The crush-to-failure time is measured in seconds.

A number of tests were carried out to fine-tune/validate the procedure and showed the following: the cylinders should be removed transversely rather than longitudinally from the potatoes; a load of 600 g, a potato cylinder length of 2.5 cm, and a 100ml loading of water in the test flask were found to be optimum and were used in all further tests.

Shear values on boiled samples of potatoes of the cultivars Maris Piper, Rooster and Homeguard were in the same rank order as the corresponding crush test values (13).

Crush-to-failure values were determined for batches (spot samples) of potatoes of six cultivars from commercial sources. The crush times (seconds) were as follows: Estima (112), Estima (133), Rooster (103), Kerr's Pink (111), Maris Piper (116), Record (118). The data show that there were larger differences between the crush values of two samples of the cultivar Estima than between the other cultivars. This indicates the potential problems facing processors of par-cooked potatoes, i.e. raw material variability in relation to susceptibility to heat treatment.

The results of the crush-to-failure test have been disseminated to potato processors and the technique has been used in-factory by two processors for determining the susceptibility to heat (in-texture-softening terms) of different batches of potatoes. This enables the adjustment of the process time for a given product texture, especially in par-cooked products.

RESISTANT STARCH

Resistant starch (RS) is that fraction of starch that is not absorbed in the small intestine of healthy individuals. It is fermented by bacteria in the large intestine with the release of energy of circa 2 kcal/g. This compares with 4 kcal/g for digestible starch. RS has many of the properties of dietary fibre (DF) but is often not classified as such because it is not cell wall material. RS, therefore, enhances the DF content of potatoes and also renders cooked/cooled/reheated potatoes "less calorific". It is only in recent years that RS has been "discovered" in foods due to better enzymatic methods of analysis. The resistance to digestion results from the retrogradation of both the amylose and amylopectin fractions of starch. Retrogradation of starch dispersions is a complex procedure and is favoured by low temperatures and high concentrations.

In view of the above, tests were carried out to measure (by an enzymatic procedure) the RS content of different potato cultivars and also the effects of boiling, warm-holding, cooling and freezing on the development of RS (14). In preliminary tests, ten individual potatoes (raw and boiled) of the cultivars Rooster and Anna were tested for RS content (results on a dry matter basis) to determine inter-tuber variation and the coefficients of variation (CV) were calculated. The mean values were: Rooster-raw (74.2%; CV = 1.94%); Rooster-cooked (10.7%; CV = 4.69%); Anna-raw (72.3%; CV = 1.43%) and Anna-cooked (10.7%; CV = 2.72%). In a second test there was no statistically significant difference in the RS content of six potato cultivars (cooked by boiling) with mean values of : Cara (10.9%), Desirée (10.4%), Maris Piper (10.0%), Rooster (10.6%), Kerr's Pink (10.6%) and Anna (10.8%). The least significant difference was 0.58.

▲ *Boiled potatoes: a source of resistant starch*

Warm-holding mashed Record potatoes at 70°C in an oven for 60 min increased RS content with values of 2.20, 2.53, 3.55, 4.49 and 4.78% (on a dry matter basis) after 10, 20, 30, 40, 50 and 60 min warm-holding respectively. These RS values are relatively low due to the absence of a cooling step. However, in slow-cooled mashed potatoes the RS content increased from 3.71% after 10 min to 6.4% after 2 hr. During this period the temperature of the mash fell from 63 to 21°C.

The effect of mashing, cooling and freezing potatoes (cultivar Record) on the development of RS was investigated in a further series of tests. The data (Table 7) show that both freezing and mashing increased RS content. The interaction between freezing and mashing was also significant in that mashing or not mashing did not influence the RS content of the frozen sample. However, for the non-frozen samples, mashing gave a higher RS content in the potatoes than not mashing. The RS values in Table 7 are much higher than those in the warm-holding and slow cooling tests above which is a reflection of the prolonged time at low temperature in the freezing/mashing experiment, i.e. chill and frozen temperatures favour the development of RS. This was confirmed (Table 8) where multiple cooking (boiling) and cooling greatly increased the RS content as did storage at 4°C (in comparison with 20°C).

These data on RS are of nutritional significance both from a dietary fibre and an energy point of view. The results are of particular importance where potatoes are being cooked-cooled and then held chilled or frozen as in potato salad production or in chilled/frozen ready meals.

Table 7: Effect of freezing and mashing on the development of resistant starch (% on dry matter) in boiled potatoes[1,2]

	Frozen	Non frozen	Mean
Mashed	15.8	14.4	15.1
Unmashed	15.1	12.9	14.0
Mean	15.5	13.7	
F-Test	■ freezing P<0.001	(LSD = 0.06)	
	■ mashing P<0.001	(LSD = 0.06)	
	■ interaction P<0.001	(LSD = 0.08)	

[1]Boiled for 8 min; freeze at -35°C for 2 hr; held at -25°C
[2]Thawed at 4°C for 24 hr

Table 8: Effect of multiple cooking-cooling on the development of resistant starch (% on dry matter) in boiled potatoes

	Storage temperature[2]		
Cook-cool[1]	4°C	20°C	Mean
Once	12.8	12.1	12.5
Twice	17.5	14.1	15.8
Three times	23.2	18.2	20.7
Mean	17.8	14.8	
F-Test: ■ cook-cool		P<0.001	(LSD = 0.17)
■ storage temp.		P<0.001	(LSD = 0.14)
■ interaction		P<0.001	(LSD = 0.24)

[1]Cook for 4 min; blast cool at -30°C for 8 min
[2]All samples were stored for 24 hr before testing

OTHER RTD ON POTATOES

The project described above is only one component of research and technical development (RTD) at The National Food Centre on the food science and technology aspects of potatoes. Recent studies include:

- searching for quality in cooked and processed potatoes (8)
- effects of nitrogen fertiliser on yield, dry matter content and flouriness of potatoes (7)
- measuring dry matter content of potatoes (6)
- dry matter and vitamin C content of ware potatoes on sale in Ireland (15)
- survey on ware potato quality in Ireland (16)
- quality and shelf-life of pre-peeled vacuum packed potatoes (17)

Comprehensive RTD on food quality, food safety and product development is also provided at The National Food Centre for Irish food companies including those in the potato processing sector. The Oak Park Research Centre of Teagasc has an extensive potato breeding programme and this includes evaluation of the processing characteristics of new potato selections and cultivars.

CONCLUSIONS

- Wide variations were obtained between potato cultivars for dry matter content, flesh colour, boiled-potato texture and starch viscological properties. There was also a variation between years.
- This variation makes it difficult for processors to deliver a consistent texture in par-cooked or mashed potato products.
- Boiled-potato texture (shear value) was correlated with potato dry matter content (-0.90), starch peak viscosity (-0.78), and degree of starch retrogradation (+0.66).
- Starch-gel compression values were correlated (+0.94) with degree of starch retrogradation as measured by a Brabender viscograph. This means that the former (rapid procedure) can be used as an index of retrogradation.
- A rapid crush-to-failure microwave technique has been developed for measuring the susceptibility to heat (in texture-softening terms) of different batches of potatoes. The procedure uses a simple apparatus and is readily applicable in-factory.
- Holding mashed potatoes at chill or frozen temperatures is conducive to the development of resistant starch, and values close to 25% (on a dry matter basis) have been obtained. These values are of nutritional significance.
- The results have been disseminated to food SMEs in the potato products and related sectors.

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